Uncovering Stops with Compressed Spectra using Deconstructed Transverse Mass Variables

Devin Walker
SLAC/Stanford University

In collaboration with
A. Ismail, A. Schwartzman, R. Schwienhorst and J. Virzi

Natural Weak Scale SUSY

- Natural SUSY requires light stops* to resolve the top quark induced quadratic divergences.

- *Compels* exploring/ruling out all of stop parameter space.

*See Dine's talk, Barbieri and Giudice, Nucl.Phys. B306; Carlos and Casas, Phys. Lett. B309; ...

2

Today's Considerations

1. R-parity conserving SUSY* with one light stop.

2. Stop pair production w/100% $\tilde{t}_1 \to t + \tilde{Z}_1$ BF

3. Semi-leptonic top pair decays.
   (Final states with one lepton + 2 b-jets + n-jets + MET)

*Techniques work for generic top partners with MET in final state.
See K. Agashe's HE4 talk on benchmarks.

3

Stop Searches

The most important parameter for stop searches*:

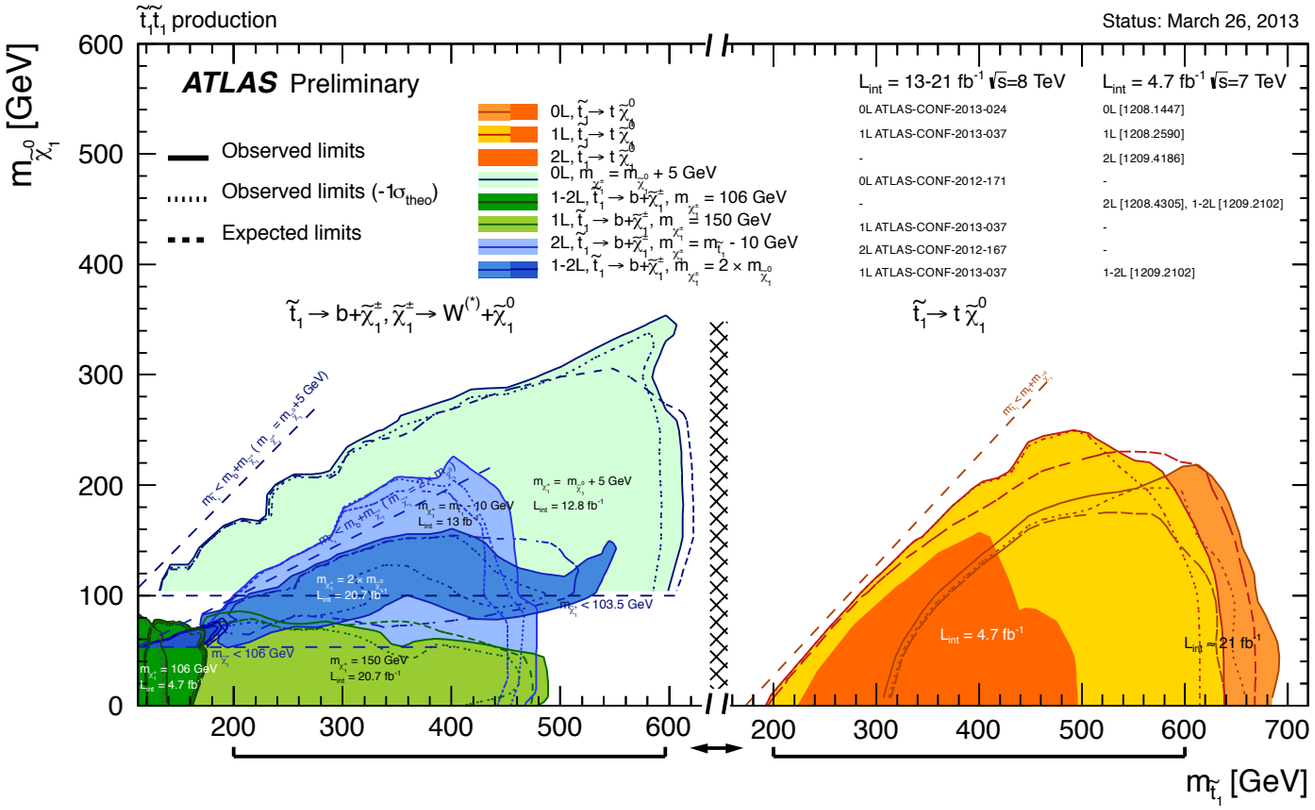
$$\Delta M_{\tilde{t}_1 Z_1} = m_{\tilde{t}} - m_{Z_1}$$

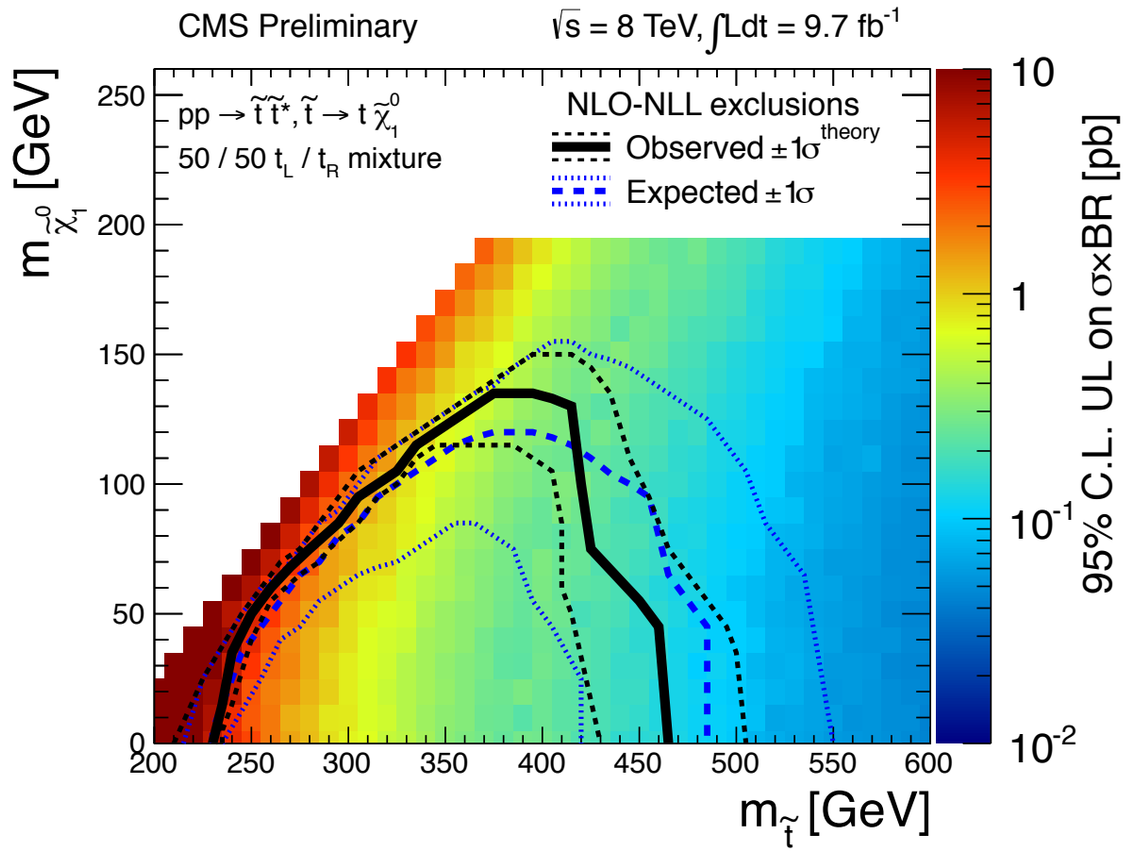
(Smallest value = compressed spectrum/experimentally difficult)

*Han, Mahbubani, Wang and Walker, JHEP 0905

4

Recent Stop Searches @ the LHC





Goal: Discuss kinematic variables/searches to enhance experimental efforts in the compressed region.

5

Talk Contents

1. Introduce deconstructed transverse mass variables*.

2. Summary of a stop search using these variables.

*A. Ismail, A. Schwartzman, R. Schwienhorst, J. Virzi and D. Walker, arXiv1304.00xx, arXiv1304.00yy

6

Deconstructed Transverse Mass Variables

7

Motivation

- Traditional missing energy searches are "cut and count" relying on a statistically significant excess of large $\not{E}_T$ events.

- Missing energy is not only a scalar but also a *vector*!

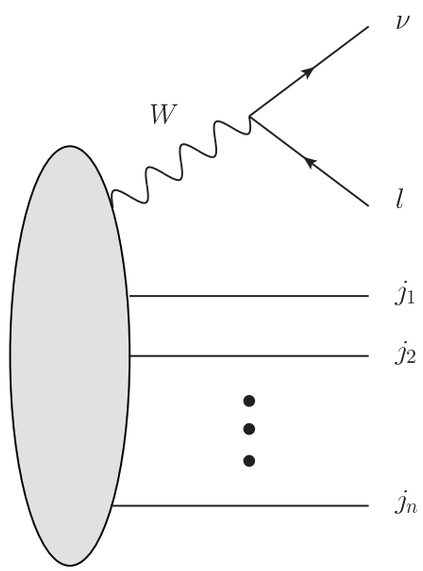
- We want to include vector information to make missing energy searches more efficient/maximize LHC.

8

W Transverse Mass

W + n-jets + MET

$$M_T^2 \;=\; 2\,E_{l\,T}\,\not{E}_T\,(1-\cos\phi)$$



- My claim: Traditional transverse mass cuts do not maximally optimize signal-to-background.

- MET can be small for compressed spectra events. Can the directional information between the missing energy vector and lepton enable better cuts?

9

Deconstructed Transverse Masses

Redefine: $$M_T^2 \;=\; 2\,E_{l\,T}\,\not\!\!E_T\,(1-\cos\phi)$$

$$Q \equiv 1 - \frac{M_{\rm T}^2}{2\,p_{l\,T}\,\not\!\!E_T} \qquad\qquad \cos\phi \equiv \frac{\vec{p}_{l\,T}\cdot\vec{\not\!\!E}_T}{p_{l\,T}\;\not\!\!E_T}$$

10

Deconstructed Transverse Masses

Redefine: $M_T^2 \;=\; 2\,E_{l\,T}\,\not\!\!E_T\,(1-\cos\phi)$

$$Q \equiv 1 - \frac{M_{\rm T}^2}{2\,p_{l\,T}\,\not\!\!E_T} \qquad \cos\phi \equiv \frac{\vec{p}_{l\,T}\cdot\vec{\not\!\!E}_T}{p_{l\,T}\;\not\!\!E_T}$$

Fixed:

Deconstructed Transverse Masses

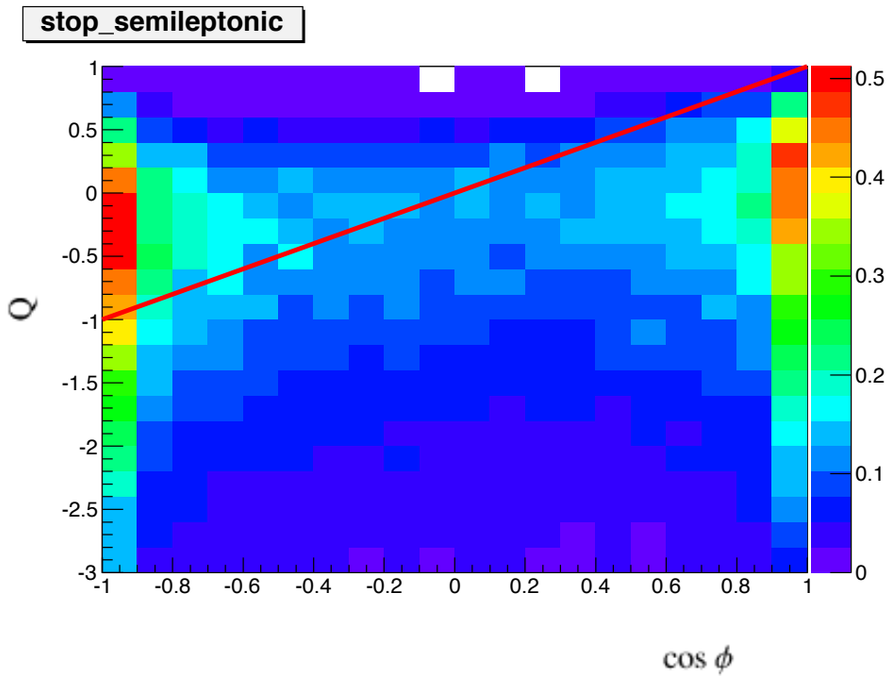
Redefine: $M_T^2 \;=\; 2\,E_{l\,T}\,\not\!\!E_T\,(1-\cos\phi)$

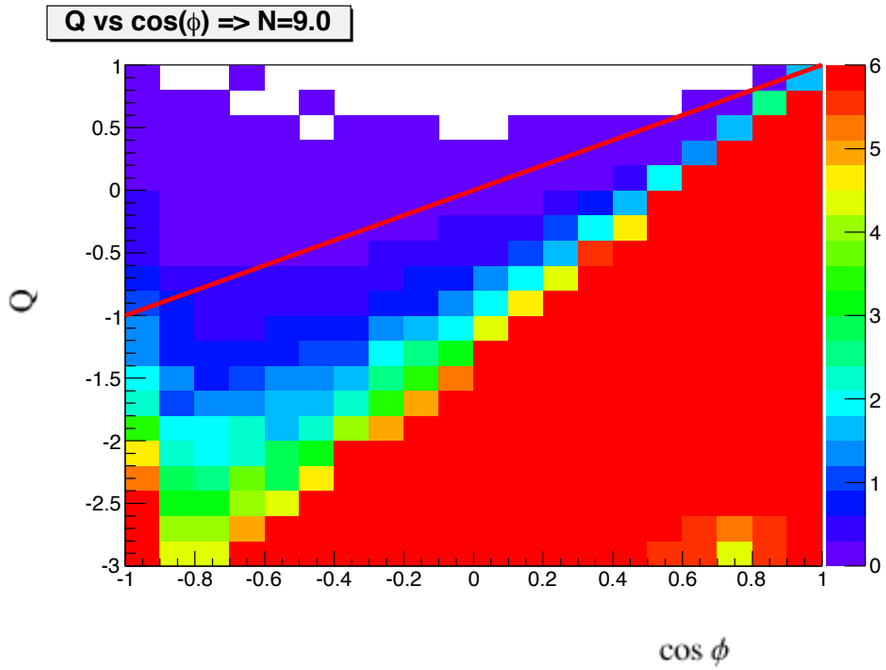
$$Q \equiv 1 - \frac{M_{\mathrm{T}}^2}{2\,p_{l\,T}\,\not\!\!E_T} \qquad \cos\phi \equiv \frac{\vec{p}_{l\,T}\cdot\vec{\not\!\!E}_T}{p_{l\,T}\;\not\!\!E_T}$$

- We essentially *deconstructed* the transverse mass into components that (maximally) preserve information about the missing energy.
  - Q goes to 1 in the large MET limit.
  - cos gives angle between MET transverse vector and lepton

12

Deconstructed Transverse Masses





stop pair production signal

400 GeV stop/200 GeV neutralino

All SM backgrounds

More on the backgrounds, simulation, cuts later.

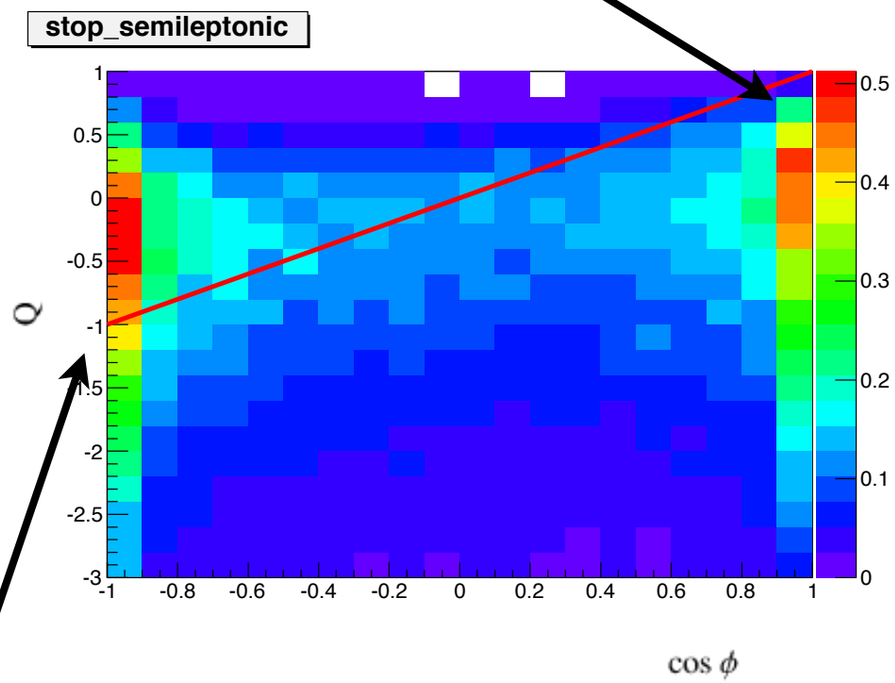
13

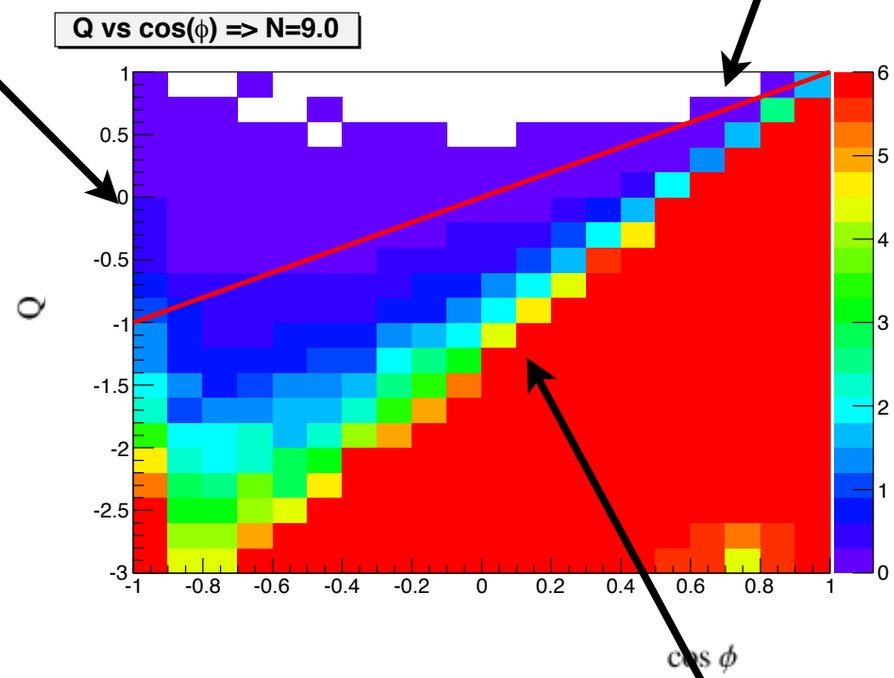
Deconstructed Transverse Masses

Signal events with boosted neutrinos

Events above red line solely from mis-measurement, clustering ...

Red line: Traditional transverse mass





Stop pair production signal

400 GeV stop/200 GeV neutralino

All SM backgrounds

Signal events w/moderately boosted DM.

Retains info on std transverse masses

More on the backgrounds, simulation, cuts later.

14

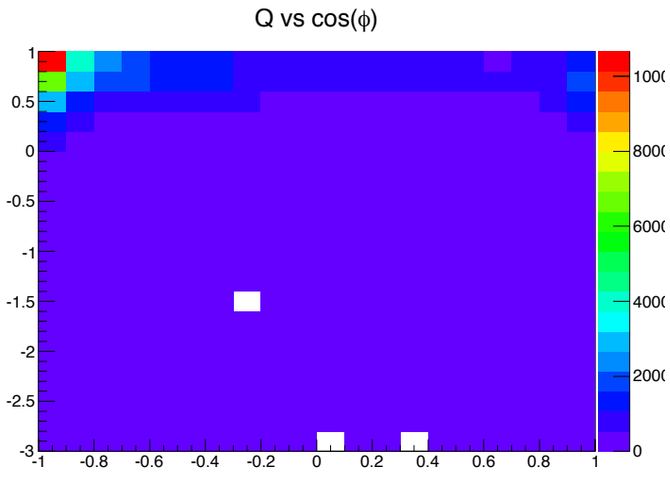
Deconstructed Transverse Masses

- What does this buy us?
  - Cut contours allow the traditional transverse mass cut to vary depending on the missing energy vector and scalar.
  - Allows cuts in the Q/cosphi plane to better isolate the signal. Cut contours can be optimized for different $\Delta M_{\tilde{t}_1 Z_1}$ searches.

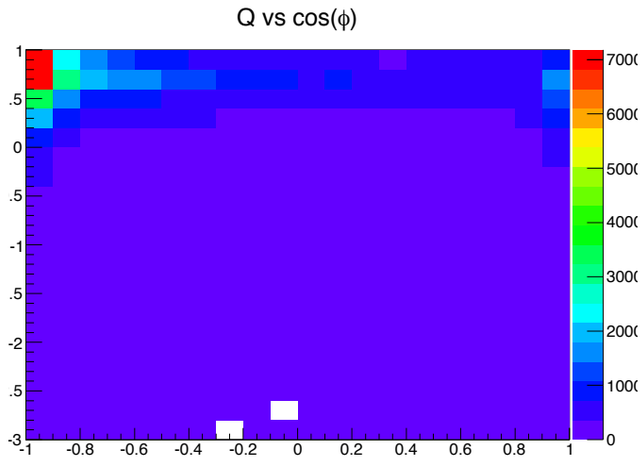
15

Deconstructed Transverse Masses

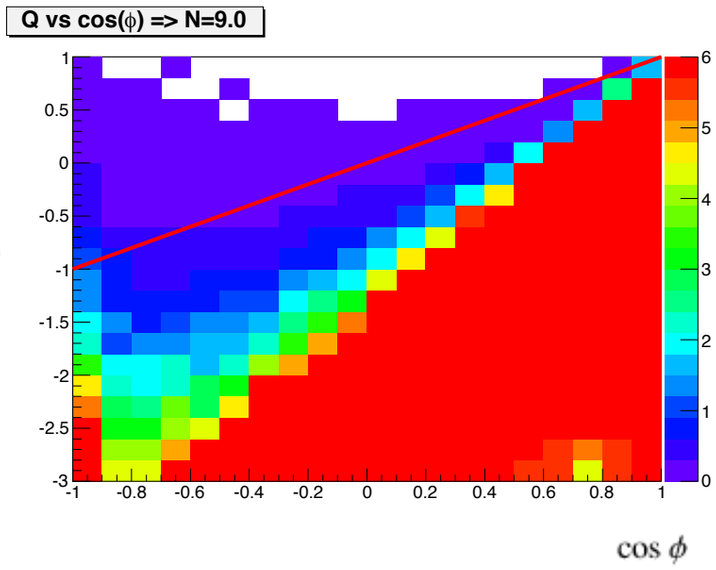
- Optimized $\Delta M_{\tilde{t}_1 Z_1}$ searches (unnormalized plots):

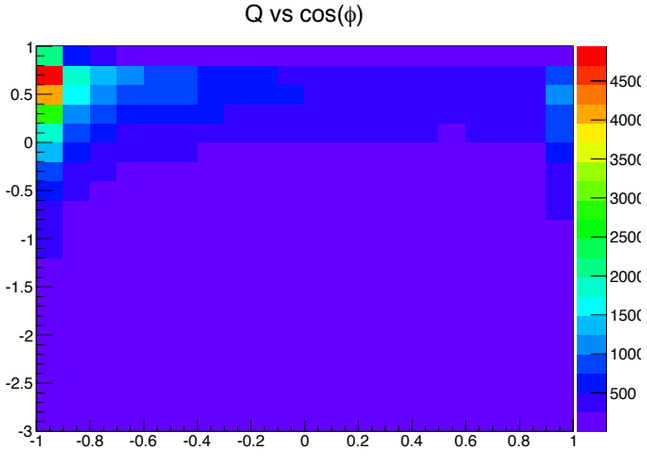


(b) 700 0 8 TeV

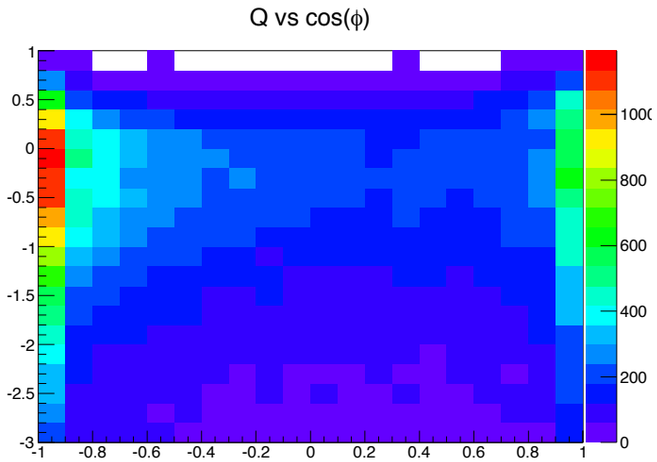


(b) 600 0 8 TeV





(f) 700 400 8 TeV



(b) 650 300 8 TeV

16

Another New Variable

SM semi-leptonic top pair production:

- Top reconstruction generates a two-fold ambiguity in the neutrino momentum.

- We choose the neutrino reconstruction to be:

$$p_{\nu L} = A' \, p_{blL}/2(E_{bl}^2 - p_{blL}^2) \pm \frac{1}{2(E_{bl}^2 - p_{blL}^2)} \times (p_{blL}^2 A'^2 + (E_{bl}^2 - p_{blL}^2)(A'^2 - 4E_{bl}^2 \not{E}_T^2))^{1/2}$$

$$A' = m_t^2 - M_{bl}^2 + 2\,\vec{p}_{blT} \cdot \vec{\not{E}}_T$$

17

Variable Definition

$$\chi_t = p_{blL}^2 A^{'2} + (E_{bl}^2 - p_{blL}^2)\,(A^{'2} - 4E_{bl}^2 \not{E}_T^2)$$

$$A' = m_t^2 - M_{bl}^2 + 2\,\vec{p}_{blT} \cdot \vec{\not{E}}_T$$

- Signal generates imaginary top reconstruction.*
- Detector smearing gives imaginary reconstruction.
- We place an optimized cut on how "imaginary" the event is to reduce smeared fakes.

*See, Han, Mahbubani, Walker, Wang, JHEP 0905 (2009)

18

Search for Stop Pair Production

19

Basic ATLAS Acceptance Cuts*

1. Four leading jets with pT > 80/60/40/25 GeV and $|\eta| < 2.5$.
2. Electron/muon pT > 25 GeV and $|\eta| < 2.47$ / $|\eta| < 2.4$.
3. Jets/leptons isolated with $\Delta R < 0.4$.
4. 1 b-tag with 75% b-tagging efficiency

All applied except for the pT > 80/60/40/25 GeV and delta_phi(jet, MET) cuts.

*See ATLAS-CONF-2012-166

20

Basic ATLAS Acceptance Cuts*

5. 130 GeV < Mjjj < 205 GeV.

6. No additional leptons with pT > 10 GeV.

7. QCD fake cut: |MET + M_T(w)| > 60 GeV.

8. delta_phi(jet, MET) < 0.8 for first two jets.

All applied except for the pT > 80/60/40/25 GeV and delta_phi(jet, MET) cuts.

*See ATLAS-CONF-2012-166

21

Basic ATLAS Acceptance Cuts*

9. M_T > 140 GeV and M_T < 250 GeV

10. MET > 150 GeV

11. MET/ Root(H_T) > 8 GeV^(1/2)

Did not apply...

*See ATLAS-CONF-2012-166

22

New Cuts

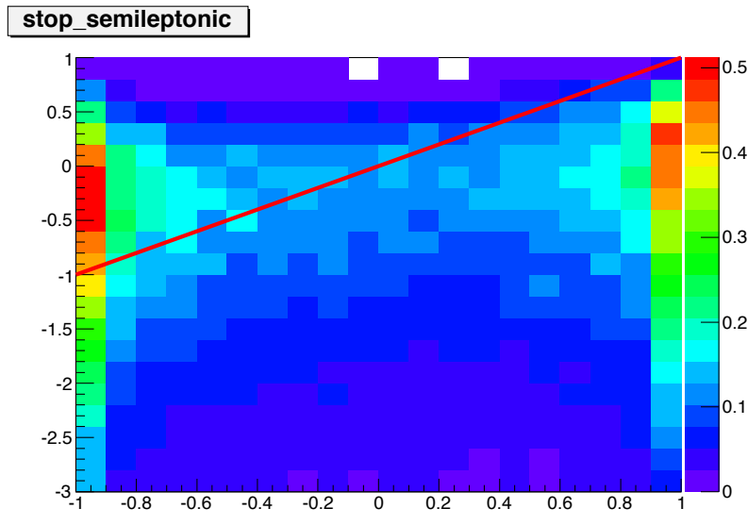
Place the following cuts in addition to ATLAS cuts:

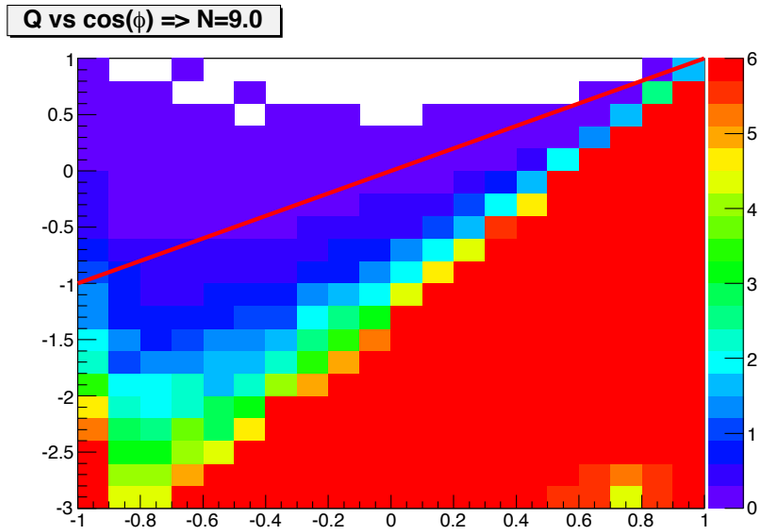
1. Q/cosphi cut.
2. χt cut.

23

New Cuts

For 400 stop and 200 GeV neutralino benchmark:





SM backgrounds included:

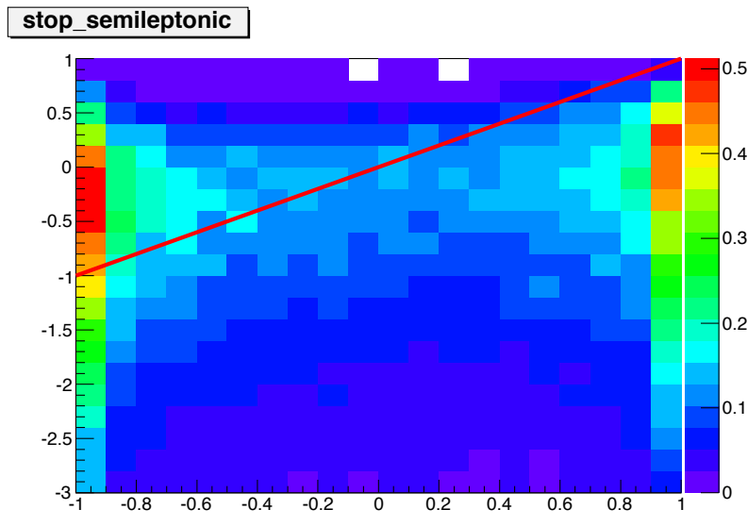
top pair (semi-)leptonic , ttV, w+ jets, z + jets, single top, ww, wz,wbb, ...

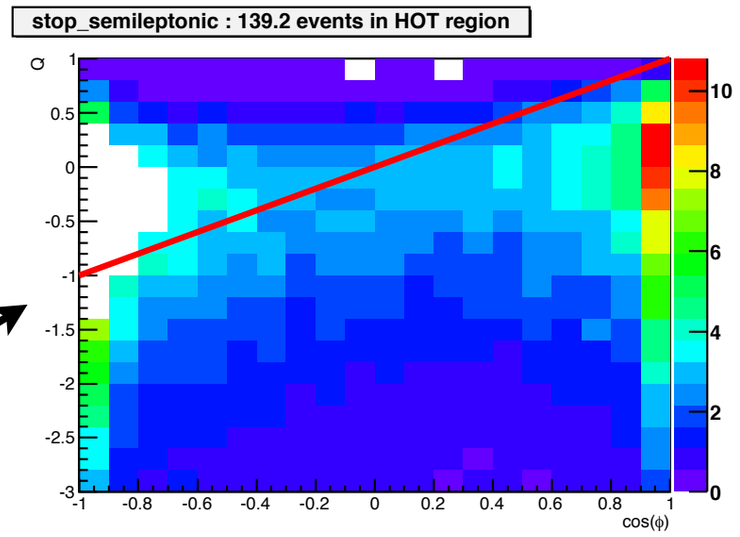
with 20/fb luminosity @ 8 TeV

24

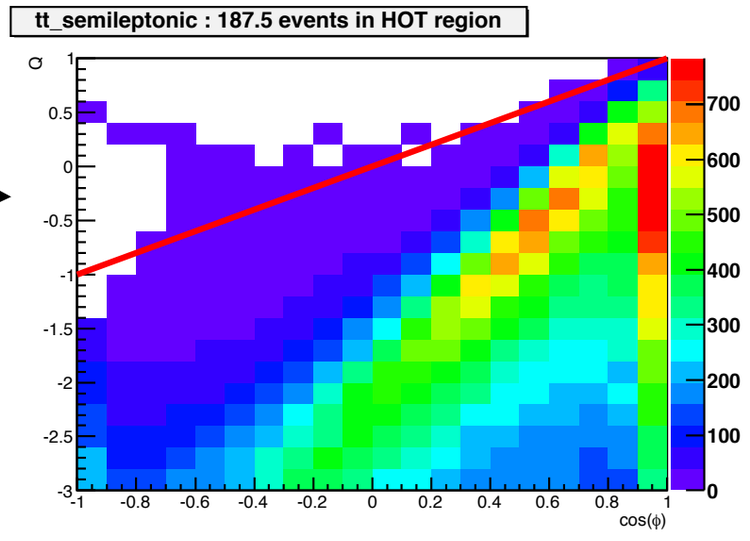
New Cuts

For 400 stop and 200 GeV neutralino:





Q/cosphi cut:
Removed this "hot region"

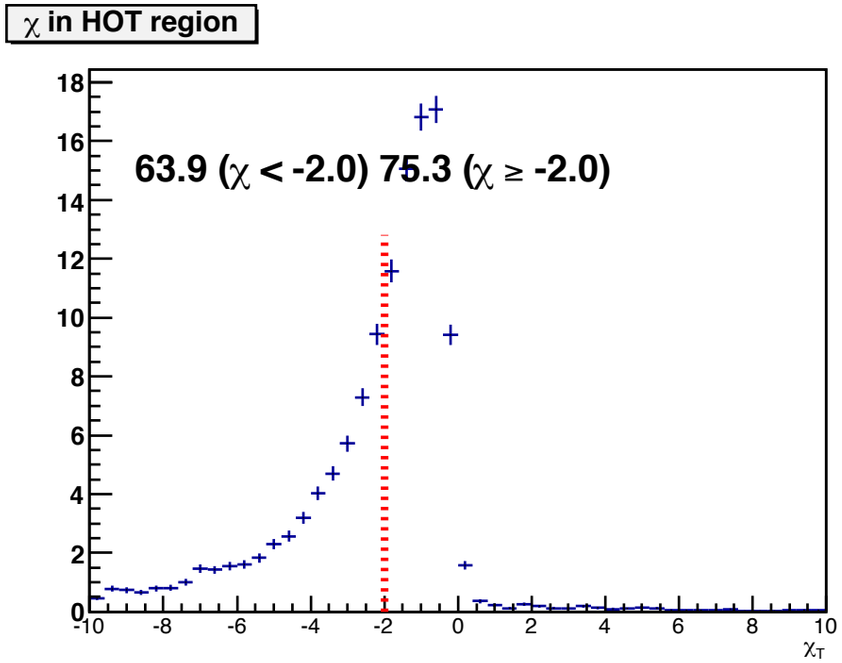


with 20/fb luminosity @ 8 TeV

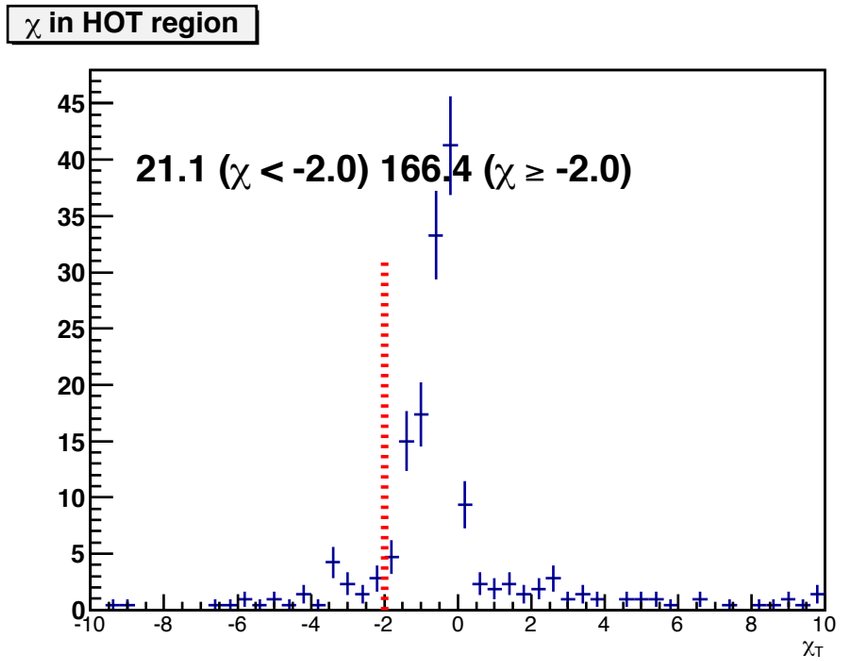
25

New Cuts

χ_t cuts:



400 GeV stop/200 GeV neutralino

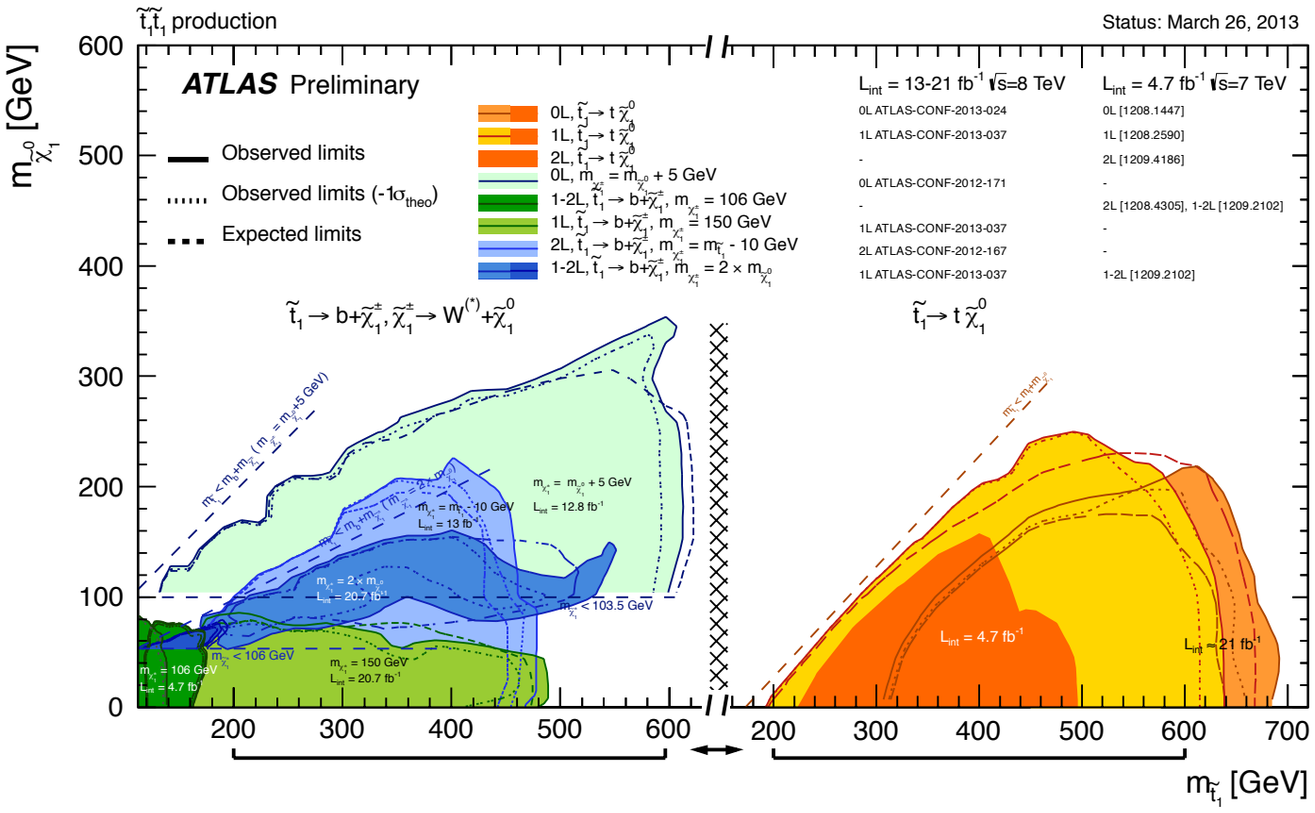


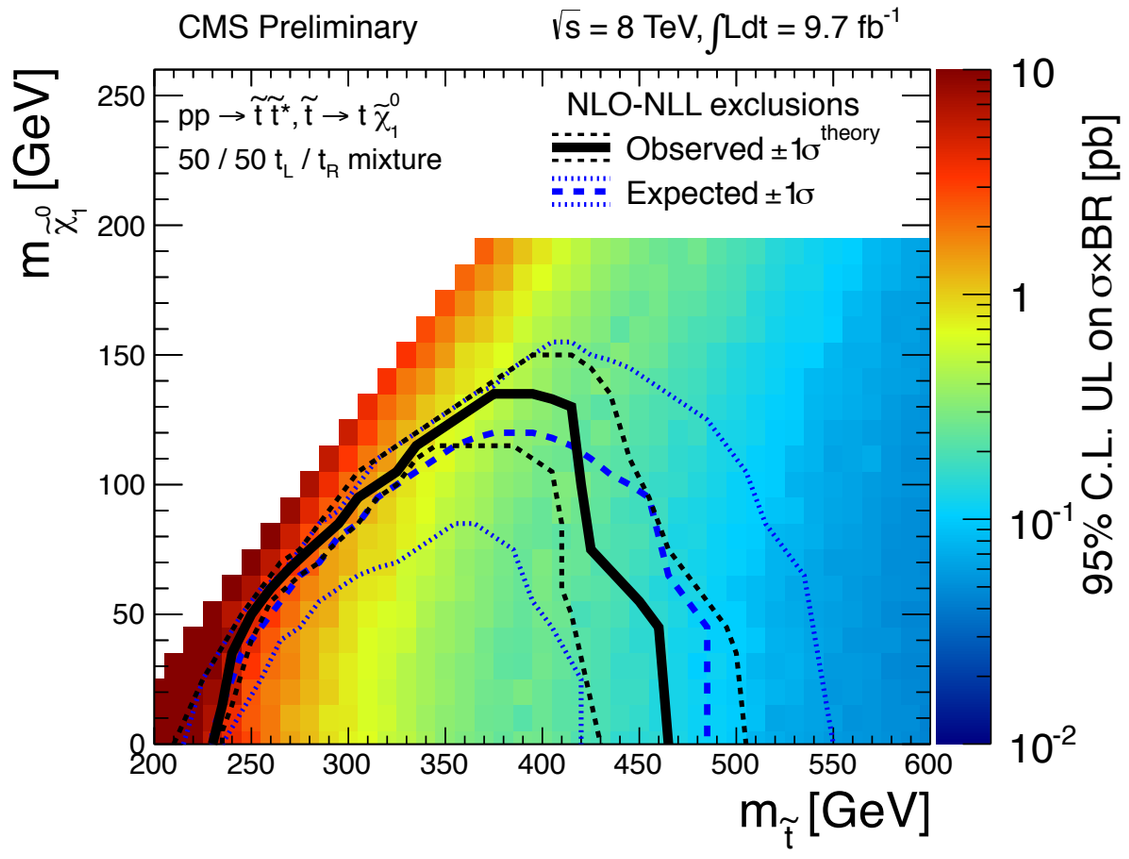
dominant top pair
semi-leptonic decay

26

Results for Signal Point

Result from (400/200) signal benchmark: S/B = 64/47 = 1.36

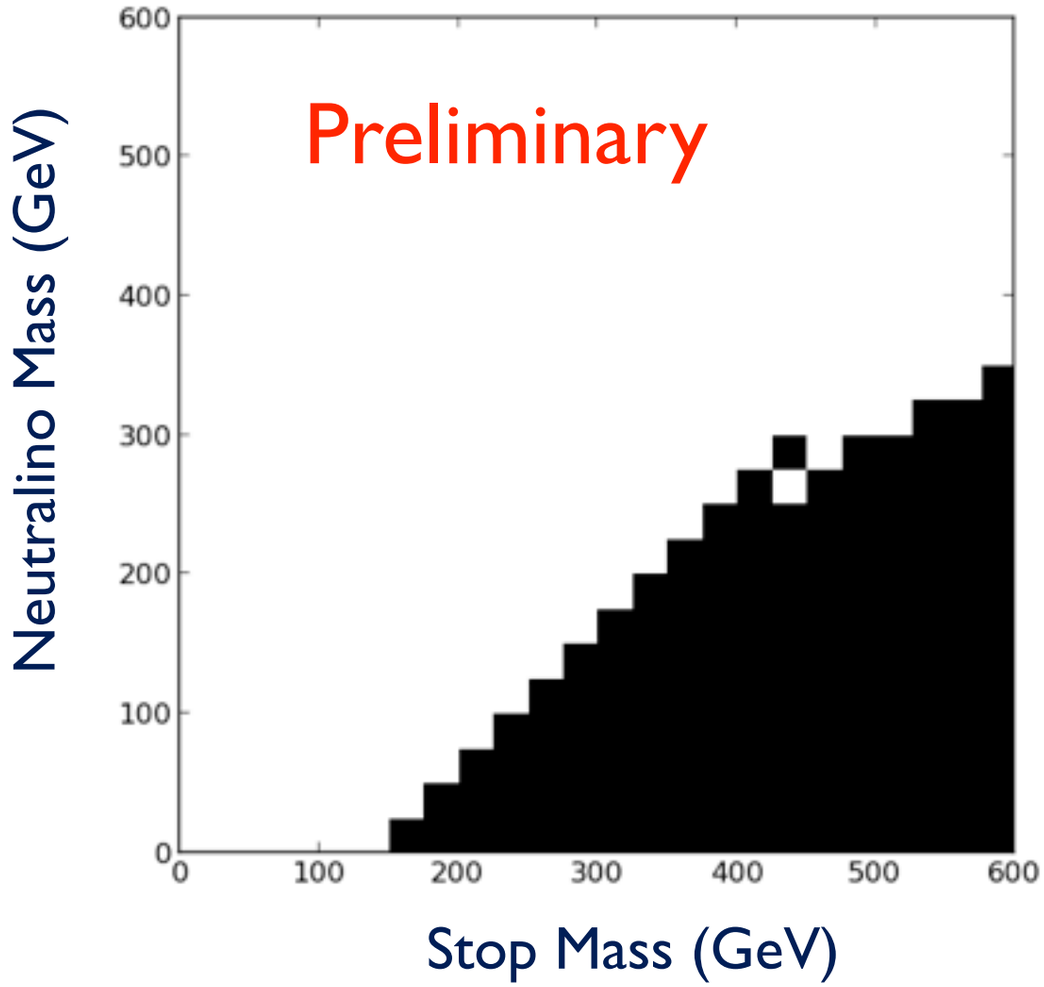


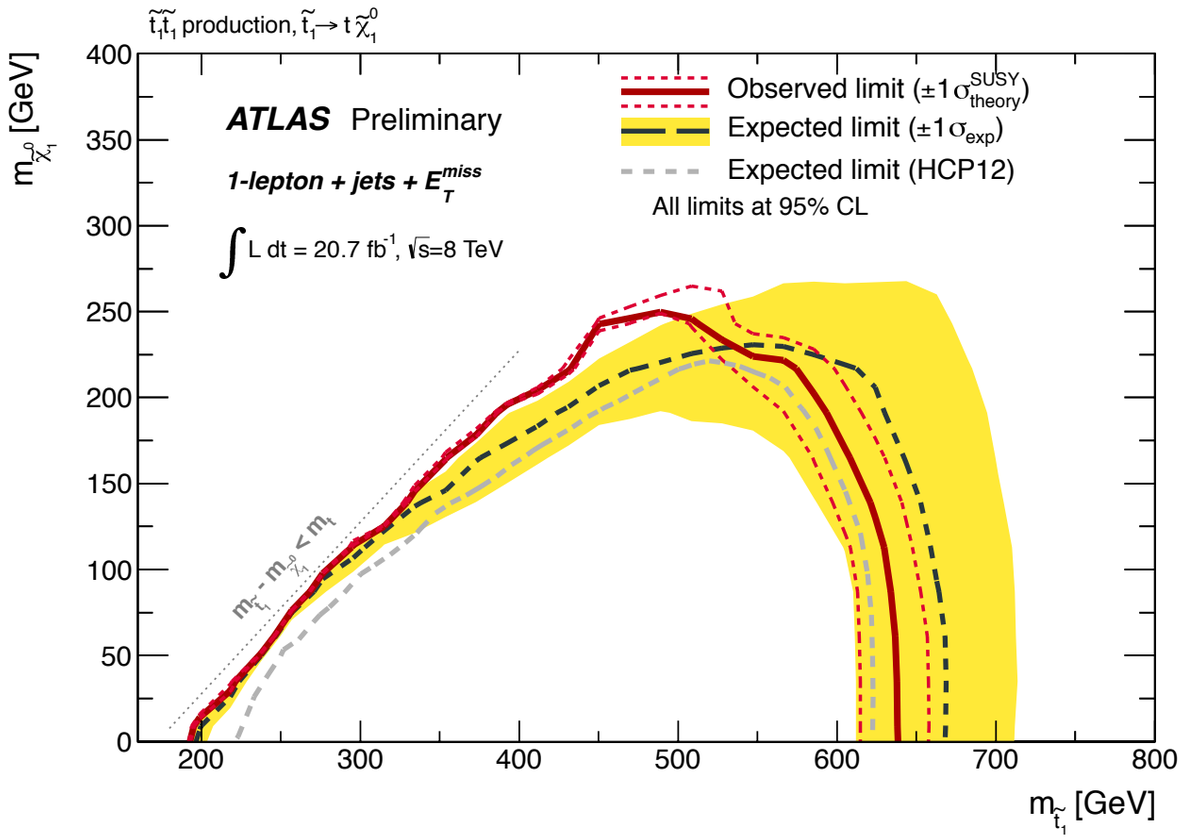


27

Most Recent Exclusion Plot*

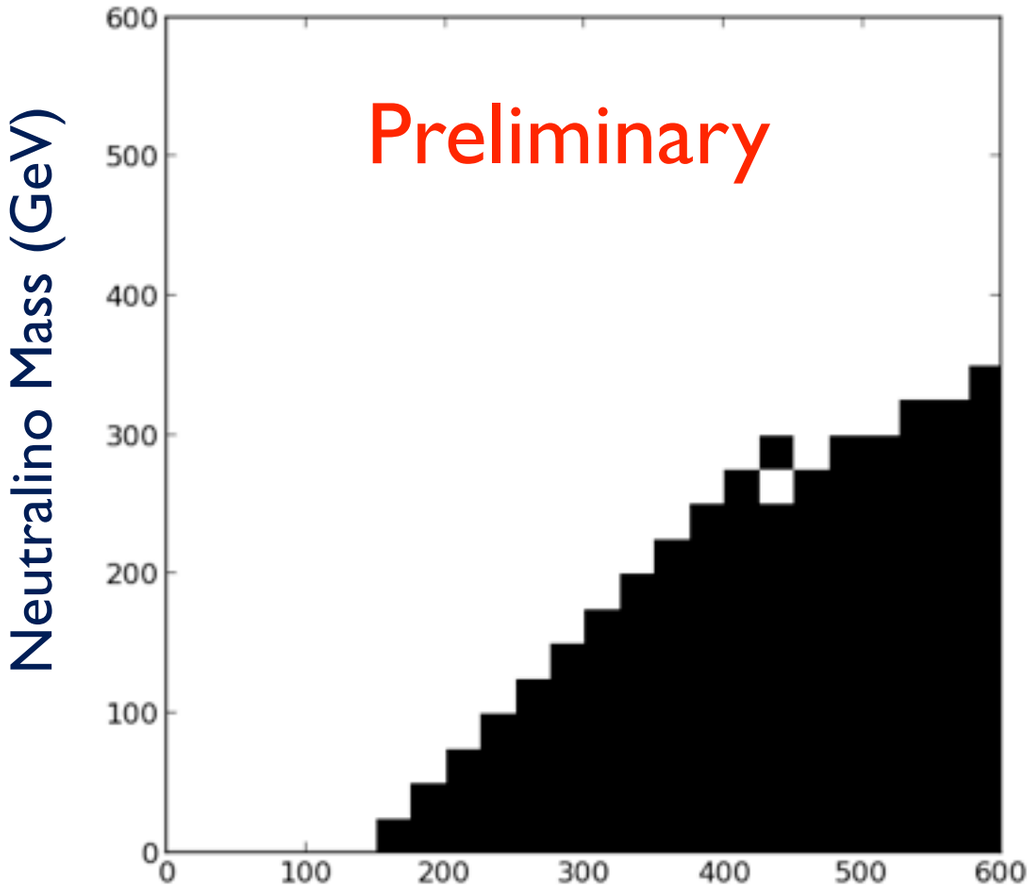
95% c.l. exclusion

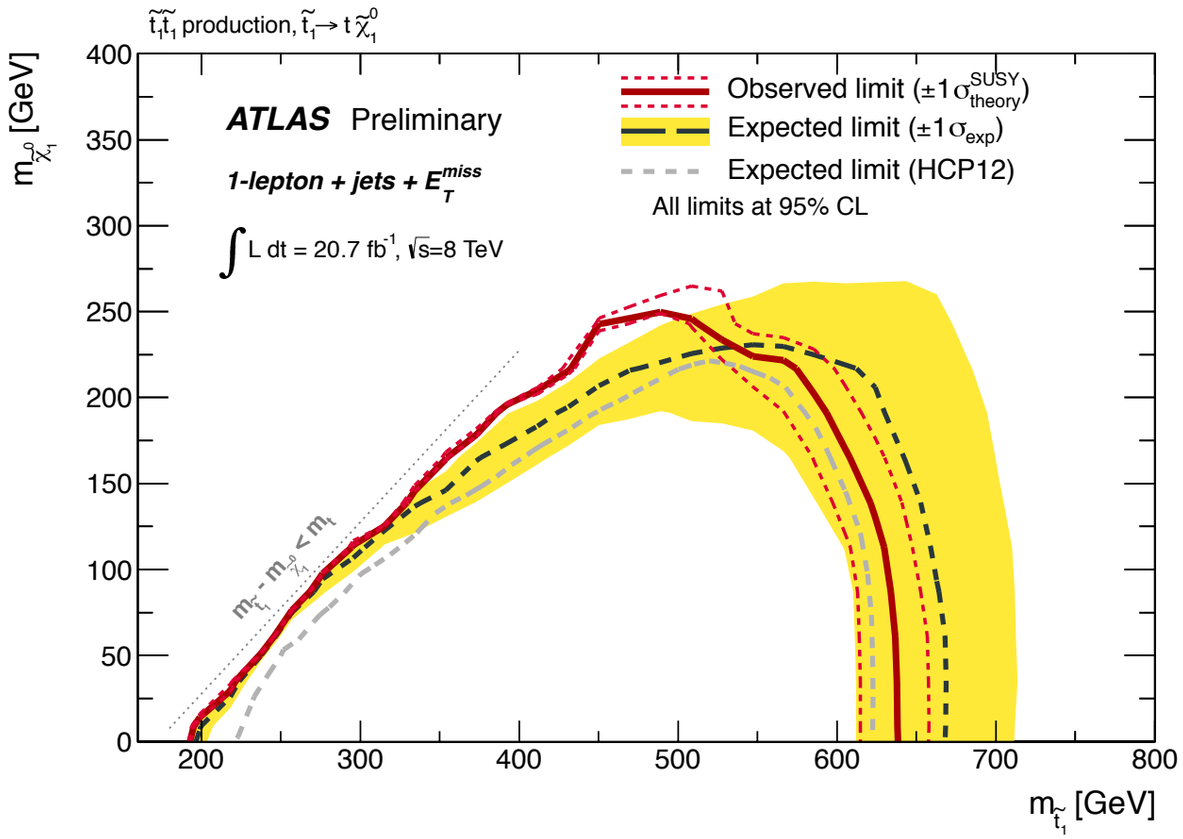




28

Most Recent Exclusion Plot*





1. Method can be applied "above the line."
2. Check extent of exclusion. Probe further?
3. Single stop exclusion for light stops (above the line as well).

29

Snowmass Contribution

- Use analysis to contribute to the reach of top partner searches with large MET.
- Contribute to compressed spectra effort.

30

Snowmass Contribution

Thank you!

31